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Morphological differences between natural populations of *Carex viridula* (Cyperaceae): effects of soil conditions

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Morphological differences among 20 populations of *Carex viridula* growing in different habitats in Poland were analysed based on examination of 365 specimens. Soil samples collected from each habitat were assayed for pH, organic matter, organic carbon, nitrogen, carbonates, and exchangeable elements (Ca, Mg, K, P). Statistical methods were used to detect patterns in morphological differences among the populations of *C. viridula* and to elucidate the effects of soil conditions on morphological characters. PCA and cluster analyses divided the specimens into two groups reflecting habitats differing in their soil conditions. A general pattern in the *C. viridula* morphology was found: habitats with soils of high contents of carbonates and exchangeable elements, and with pH exceeding 7.0, supported specimens usually having three or two (more seldom four) female spikes spaced widely apart, and long, usually peduncled, male spikes.

Introduction

Carex viridula belongs in the *Carex flava* complex of the *Ceratocystis* section (Chater 1980, Egorova 1999). The taxonomic treatment of this sedge species has been widely discussed in the literature (e.g. Davies 1953b, Palmgren 1959, Schmid 1983, Crins & Ball 1989b, Egorova 1999). The discussion revolved around three main taxonomic concepts of *C. viridula*: (1) broad (*C. viridula* aggregate), (2) narrow (*C. viridula s. stricto*), and (3) intermediate. The *C. viridula* aggregate contains also *C. lepidocarpa* and *C. demissa* recognized as *C. viridula* subsp. *brachyrrhyncha* var. *lepidocarpa* (= *C. viridula* subsp. *brachyrrhyncha* var. *elatior*) and *C. viridula* subsp. *oedocarpa* (*see* Schmid 1983, 1986, Crins & Ball 1989a, 1989b), respectively. However, the status of *C. lepidocarpa* and *C. demissa* as distinct species was confirmed by recent molecular and cytogenetic studies (Jimenez-Mejías *et al.* 2012). The narrow concept of *C. viridula* implies the separation of *C. bergrothii* (and of *C. scandinavica* in some treatments; Davies 1953a, 1953b, Palmgren 1959, Chater 1980, Egorova 1999) which, according to the intermediate concept, is a variety (Pykälä & Toivonen 1994, Hedrén 2003), or a subspecies of *C. viridula* (Koopman 2011).

Carex viridula has an almost circumpolar distribution (Hultén & Fries 1986). It grows

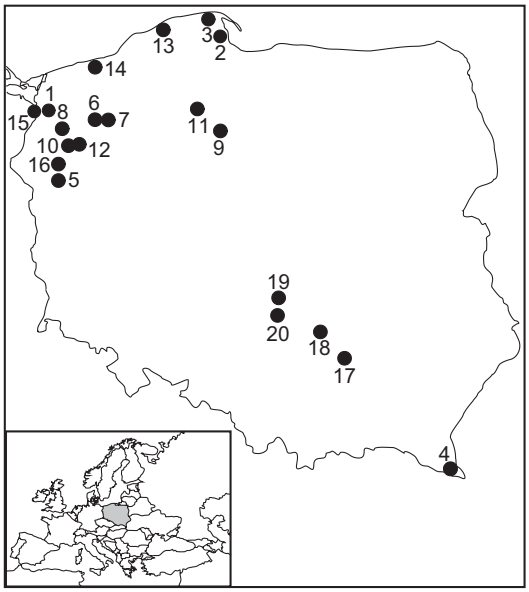

Fig. 1. Locations of *Carex viridula* sampling sites; *n* = number of specimens. Szczecin Lowland, 53°34´N, 14°42´E, *n* = 19; 2. Gdańsk Seashore, 54°39´N, 18°27´E, *n* = 10; 3. Gdańsk Seashore, 54°49´N, 17°58´E, *n* = 27; 4. Bieszczady Mountains, 49°03´N, 22°42´E, *n* = 10; 5. Myślibórz Lakeland, Chłop Lake, 52°59´N, 14°54´E, *n* = 22; 6. Ińsko Lakeland, Długie Lake, 53°26´N, 15°35´E, *n* = 21; 7. Ińsko Lakeland, Kiełpino Lake, 53°26´N, 15°37´E, *n* = 25; 8. Szczecin Lowland, Miedwie Lake, 53°13´N, 14°55´E, *n* = 19; 9. Kaszuby Lakeland, Piaseczno Lake, 53°39´N, 18°15´E, *n* = 13; 10. Szczecin Lowland, Zaborsko Lake, 53°10´N, 15°00´E, *n* = 12; 11. Kaszuby Lakeland, Gołuń Lake, 54°00´N, 17°57´E, *n* = 24; 12. Szczecin Lowland, 53°09´N, 15°00´E, *n* = 15; 13. Słowińskie Seashore, 54°44´N, 17°25´E, *n* = 30; 14. Koszalin Seashore, 54°12´N, 15°42´E, *n* = 24; 15. Szczecin Lowland, 53°33´N, 14°20´E, *n* = 28; 16. Myślibórz Lakeland, Tchórzyno Lake; 53°00´N, 14°51´E; *n* = 17; 17. Małopolska Upland, 50°31´N, 20°34´E, *n* = 17; 18. Małopolska Upland, 50°58´N, 19°56´E, *n* = 10; 19. Małopolska Upland, 51°06´N, 18°46´E, *n* = 12; 20. Małopolska Upland, 51°12´N, 18°47´E, *n* = 10.

along shores of lakes and seas as well as in wet meadows, mires, and peatlands. It has the ability to colonise different habitats (moist or wet, from acidic to alkaline, sandy or organic; Schmid 1984a). *Carex viridula* forms small, temporally and spatially isolated populations of varying morphology (e.g. Palmgren 1959, Havlícková 1982, Schmid 1984a, 1984b, 1986, Crins & Ball 1989a, Hedrén 2003, Więcław 2011).

Thus, the ecological niche of *C. viridula* is wide, which is reflected in its high phenotypic plasticity. With this in mind, our study was aimed at analysing the effects of soil conditions on the morphology of *C. viridula* in populations growing in different habitat types. In this study, *C. viridula* is treated according to the intermediate taxonomic concept expounded by Koopman (2011).

Material and methods

Field studies and collection of specimens

We conducted our field studies in 2009–2011 on 20 natural populations of *Carex viridula* in Poland (Fig. 1). Voucher specimens from each population were deposited in the University of Szczecin Herbarium. We collected and measured a total of 365 *C. viridula* specimens, all at a similar developmental stage. We collected the specimens from the widest possible range of habitats: from intermediate and carbonate-rich peatlands to wet meadows, mires, drying ponds, peat-containing or sandy shores of lakes to dune troughs. The number of specimens collected from an individual site ranged from 10 to 30, depending on the local abundance of the sedge. To reduce the probability of collecting individuals of the same clone, our sampling sites within a population range were chosen so that they were 3–6 m apart from one another.

Morphological characters

Our study was performed on operational taxonomic units (OTUs). An OTU is a specimen characterised by 29 morphological traits (26 quantitative and 3 qualitative; Table 1). The collected specimens were measured to the nearest 0.01 mm (the size of utricles, glumes, spikes, and peduncles and the width of leaves and bracts) under a stereomicroscope (ZEISS Discovery V12). Plant height and lengths of leaves and bracts were measured with a ruler to the 0.1 cm. Five utricles and five glumes were detached from the mid-part of a female spike of each specimen. Also five male glumes were detached from the mid-part of a male spike of each speci-

men. For the analysis, the measurements of those parts were averaged. Utricles from the mid-part of a spike are considered to be least variable and are therefore most commonly used in biometry (*see* Blackstock & Ashton 2010).

Soil sample analyses

The soil was sampled at each site to the depth of 10 cm. The samples, dried at room temperature, were crushed and fractions coarser than 2 mm were removed. The following properties were determined from the samples prepared this way: pH (in H_2O and in 1 N KCl solution), organic matter content (by loss on ignition), exchangeable elements (P, K, Mg, and Ca, using ASA), carbonates (Scheibler's method), and total C and N contents (CHNS elemental analyser, Costech). The latter assay provided data for calculation of the C/N ratio. The ratio between organic carbon and nitrogen in soil humus is one of the major indicators of soil quality. The lower the ratio, the more fertile the soil.

Statistical analyses

To assess the degree of variability in each morphological trait analysed, we calculated coefficients of variation (CV) separately for each population and for the entire data set. Differences between means of the variables analysed in all the populations and in population groups identified based on the soil parameters were tested with one-way ANOVA.

We used all the variables (365 individuals and 40 characters) to perform the principal com-

Table 1. Characters used in the phenetic analyses.

Characters	Abbreviation
Culm height (cm)	CH
Cauline leaf width (cm)	CLW
Cauline leaf length (cm)	CLL
Culm hight to leaf length ratio (1 = leaves shorter or equal to half the length of culm; 2 = leaves 3/4 the length of culm; 3 = equal; 4 = longer)	C/L
Inflorescence length (cm)	IL
Male spike length (cm)	MSL
Male spike width (cm)	MSW
Male spike peduncle length (cm)	MSPL
Number of female spikes	NFS
Distance between two upper female spikes (cm)	DUFS
Distance between two lower female spikes (cm)	DLFS
Lowest female spike length (cm)	LFSL
Lowest female spike width (cm)	LFSW
Lowest female spike peduncle length (cm)	LFSPL
Lowest female spike bract length (cm)	LFSBL
Lowest female spike bract width (cm)	LFSBW
Lowest female spike bract sheath length (cm)	LFSBSL
Length of lowest bract to length of inflorescence ratio (1 = bract shorter from inflorescence; 2 = equal; 3 = longer, but no more than twice the length; 4 = much longer, more than twice the length of inflorescence)	B/I
Uppermost female spike length (cm)	UFSL
Uppermost female spike width (cm)	UFSW
Second female spike bract length (cm)	SFSBL
Second female spike bract width (cm)	SFSBW
Utricle length (mm)	UL
Utricle beak length (mm)	UBL
Ratio of beak length to utricle length (%)	B/U
Female spike glume length (mm)	FSGL
Female spike glume width (mm)	FSGW
Male spike glume lenght (mm)	MSGL
Male spike glume width (mm)	MSGW

ponents analysis (PCA) and the cluster analysis. OTUs were classified using Ward's minimum variance, based on the Manhattan distance.

For the purpose of our analysis, we standardized the data so that each variable would have a mean of 0 and a standard deviation of 1. Calculations were performed using Statistica ver. 8.0 for Windows (StatSoft 2007).

Results

Range of variability of the morphological traits

Coefficients of variation of DUFS, DLFS, LFSPL, LFSBSL, IL, and MSPL calculated for the entire set of data (CV_0) and for each population separately ($CV_{1–20}$) were relatively high (Table 2). The least variable traits were those of the utricles (UL, UBL, B/U), glumes (FSGL, FSGW, MSGL, MSGW), and spikes (LFSL, LFSW, UFSL, UFSW, MSW). Specimens belonging to populations 1, 8, 5, 3, and 11 were highly variable, the coefficients of variation for some of the traits exceeding 100%. The least variable were individuals representing populations 2, 4, and 9 (Table 2).

All the studied traits differed significantly among populations (Table 3).

Soil parameters

Concentrations of $CaCO_3$ and Ca were high in samples 16 and 5 (Table 4). In addition, carbonates were found to occur also in samples 4, 8, 12, and 14. The concentrations of assimilable elements varied: the highest Mg contents were found in samples 4, 5, and 16; high concentrations of K were found in samples 2, 4, and 14, whereas samples 1, 7, 8, and 11 had high P

Table 2. Coefficients of variations (CV_0: coefficient of variation calculated for the entire data set; CV_1, CV_2, …, CV_{20}, coefficients of variation calculated for populations 1, 2, …, 20, respectively).

Characters	CV_0	CV_1	CV_2	CV_3	CV_4	CV_5	CV_6	CV_7	CV_8	CV_9	CV_{10}	CV_{11}	CV_{12}	CV_{13}	CV_{14}	CV_{15}	CV_{16}	CV_{17}	CV_{18}	CV_{19}	CV_{20}
CH	48	31	30	51	20	23	44	55	51	39	20	32	21	25	53	27	75	42	20	32	33
CLW	14	13	9	11	11	17	11	11	12	6	12	7	10	15	14	17	7	10	15	14	11
CLL	36	26	17	20	19	33	30	27	26	27	18	21	21	17	34	26	66	43	22	24	17
C/L	35	41	39	47	35	35	32	36	27	25	29	15	31	36	26	29	23	30	25	26	19
IL	71	78	31	79	23	48	77	33	75	30	60	62	59	47	74	42	29	45	88	75	86
MSL	36	29	35	32	15	18	26	17	29	19	20	25	32	35	23	16	16	27	44	37	18
MSW	16	9	9	22	10	9	12	17	16	11	14	10	11	12	13	11	11	19	14	14	12
MSPL	112	62	61	15	19	129	7	6	61	50	21	36	11	39	58	54	28	48	48		13
NFS	27	17	28	32	25	21	19	14	25	15	17	21	15	35	28	17	25	25	31	21	19
DUFS	126	105	69	112	60	153	69	60	123	33	47	71	56	77	39	35	79	51	56	73	49
DLFS	122	136	24	156	61	57	102	59	128	67	115	119	97	70	134	69	57	75	112	102	162
LFSL	18	18	5	15	13	18	16	22	16	12	7	13	12	17	20	17	12	10	15	13	15
LFSW	11	7	6	9	5	9	7	10	8	13	7	8	9	6	8	11	8	7	13	9	7
LFSPL	135	77	30	89	18	126	70	50	121	72	18	131	67	51	136	67	44	42	126	44	56
LFSBL	43	49	28	28	31	31	44	35	29	31	29	33	27	36	36	34	40	44	30	27	29
LFSBW	14	14	8	11	13	15	10	10	14	7	7	6	9	14	13	17	7	14	14	15	7
LFSBSL	83	86	48	63	74	72	57	66	78	60	64	63	65	76	46	81	64	78	61	56	72
B/I	20	25	10	25	11	15	28	15	27	14	10	15	14	8	16	22	17	13	32	35	11
UFSL	19	20	12	12	11	19	21	15	15	19	7	16	10	21	21	17	12	10	16	13	15
UFSW	11	10	7	10	7	9	9	8	6	10	7	7	9	10	11	10	7	6	7	8	8
SFSBL	47	25	25	35	43	45	47	41	40	35	25	61	47	50	43	40	41	49	41	54	31
SFSBW	42	44	29	41	43	32	62	55	42	36	25	50	32	32	36	44	35	32	25	61	32
UL	12	7	7	9	4	9	11	10	8	16	6	6	11	8	8	12	8	7	7	10	3
UBL	16	12	7	13	8	13	16	13	14	26	10	7	14	12	10	14	14	10	13	17	10
B/U	9	10	4	10	7	8	9	6	9	12	5	5	8	6	7	7	9	11	7	8	9
FSGL	13	8	9	8	17	9	12	14	9	15	5	7	17	9	11	11	9	5	7	11	8
FSGW	11	9	9	9	8	7	13	8	10	8	5	9	13	7	14	6	11	8	13	6	7
MSGL	11	14	6	5	11	7	6	10	6	4	7	8	19	9	6	8	10	12	10	10	11
MSGW	9	5	2	6	8	7	9	6	8	6	5	8	13	7	8	8	14	7	10	7	5

Table 3. Results of one-way ANOVA (F_0 = for all the populations studied; F_1 = for two groups of populations separated by soil parameters; F_2 = for two subgroups in cluster I; cf. Fig. 4). Results whose $p < 0.05$ are indicated with asterisks (*).

Characters	F_0 (df1 = 19, df2 = 345)	p	F_1 (df1 = 1, df2 = 363)	p	F_2 (df1 = 1, df2 = 151)	p
CH	13.54*	< 0.0001	9.85*	0.0018	15.49*	0.0001
CLW	6.62*	< 0.0001	1.72	0.1910	13.83*	0.0003
CLL	15.15*	< 0.0001	18.28*	< 0.0001	7.01*	0.0090
C/L	7.56*	< 0.0001	2.42	0.1206	0.23	0.6316
IL	3.38*	< 0.0001	0.49	0.4853	1.97	0.1622
MSL	16.39*	< 0.0001	8.27*	0.0043	1.74	0.1895
MSW	9.18*	< 0.0001	12.63*	0.0004	10.15*	0.0018
MSPL	3.91*	< 0.0001	5.11*	0.0244	8.10*	0.0051
NFS	6.38*	< 0.0001	25.07*	< 0.0001	4.47*	0.0362
DUFS	3.24*	< 0.0001	12.93*	0.0004	10.43*	0.0015
DLFS	3.12*	< 0.0001	2.78	0.0962	0.13	0.7206
LFSL	7.59*	< 0.0001	1.19	0.2763	5.68*	0.0184
LFSW	11.82*	< 0.0001	0.33	0.5654	2.57	0.1113
LFSPL	3.49*	< 0.0001	0.01	0.9176	4.41*	0.0375
LFSBL	8.95*	< 0.0001	2.77	0.0970	5.95*	0.0159
LFSBW	5.77*	< 0.0001	0.38	0.5387	1.58	0.2114
LFSBSL	5.16*	< 0.0001	1.54	0.2152	18.30*	< 0.0001
B/I	2.47*	0.0007	3.67	0.0561	0.92	0.3379
UFSL	8.11*	< 0.0001	4.94*	0.0268	26.13*	< 0.0001
UFSW	12.35*	< 0.0001	3.57	0.0596	5.24*	0.0234
SFSBL	2.83*	0.0001	0.98	0.3231	7.76*	0.0060
SFSBW	1.89*	0.0137	4.58*	0.0331	0.34	0.5581
UL	13.14*	< 0.0001	0.03	0.8722	0.10	0.7515
UBL	9.24*	< 0.0001	1.43	0.2330	0.35	0.5564
B/U	5.24*	< 0.0001	5.22*	0.0230	1.28	0.2589
FSGL	11.79*	< 0.0001	0.72	0.3971	9.84*	0.0021
FSGW	8.68*	< 0.0001	4.97*	0.0264	0.96	0.3278
MSGL	8.32*	< 0.0001	1.39	0.2394	15.76*	0.0001
MSGW	5.26*	< 0.0001	1.10	0.2945	5.41*	0.0213

Table 4. Soil parameters measured at individual *Carex viridula* collection sites. C = carbon, *N* = nitrogen, OM = organic matter content, C/*N* = carbon/nitrogen ratio, pH = soil pH, $CaCO_3$ = carbonates, P = exchangeable phosphorus, K = exchangeable potassium, Mg = exchangeable magnesium, Ca = exchangeable calcium.

Site	Soil parameters										
	C (%)	OM (%)	N (%)	C/N	pH-KCl	pH-H_2O	$CaCO_3$ (%)	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	Ca (mg kg^{-1})
1	3.9	6.7	0.3	11.7	6.2	6.8	0.0	40.0	28.0	47,4	260.0
2	37.3	64.2	2.5	18.8	5.5	5.9	0.0	15.3	318.9	1198.7	5149.0
3	0.5	0.8	0.1	11.7	4.6	5.0	0.0	4.4	27.7	63.0	98.3
4	4.8	8.2	0.2	18.9	7.3	7.7	16.4	28.3	203.8	4005.2	21066.6
5	15.4	26.6	0.4	36.9	7.4	7.4	81.5	15.3	36.4	3190.2	99971.3
6	1.3	2.3	0.1	14.0	5.0	5.4	0.0	8.7	37.4	59.5	206.5
7	0.7	1.1	0.1	14.7	6.2	6.4	0.0	36.1	16.2	30.4	802.1
8	6.5	11.1	0.4	18.5	7.3	7.4	17.8	52.3	27.4	836.8	22554.4
9	0.2	0.4	0.0	13.8	5.9	6.7	0.0	6.5	37.4	59.8	136.9
10	37.2	64.2	2.8	13.4	6.9	7.2	0.0	19.6	60.6	909.2	22296.0
11	40.6	0.0	2.7	15.0	5.5	6.0	0.0	50.0	128.1	95.6	198.0
12	28.2	48.7	1.8	15.6	7.2	7.3	31.8	17.4	51.8	1737.4	51124.8
13	0.1	0.1	0.0	5.5	4.4	5.8	0.0	6.5	38.3	29.7	45.0
14	2.6	4.5	0.1	24.6	7.3	7.4	9.1	28.3	244.6	1734.7	13620.2
15	0.1	0.2	0.0	8.5	6.9	7.0	0.0	10.9	46.7	60.7	112.4
16	14.7	25.3	0.2	71.0	7.8	7.8	85.0	6.5	20.1	3366.6	110048.9
17	0.5	0.8	0.0	11.9	6.5	6.9	0.0	6.5	21.3	47.0	437.4
18	14.3	24.6	1.0	14.1	4.8	5.3	0.0	8.7	41.9	43.5	2129.7
19	2.6	4.4	0.2	12.8	4.5	5.4	0.0	6.5	34.5	36.2	91.3
20	6.3	10.8	0.4	17.3	4.9	5.3	0.0	6.5	45.9	49.9	393.9

concentrations. The soil at site 16 proved least fertile, as indicated by the high C/N ratio. The soil pH ranged from 7.8 at site 16 to 4.4 at site 13 (Table 4).

Principal component and cluster analyses

The first two principal components were found to explain more than 46% of total variation (Fig. 2). Two partly overlapping clusters were formed along the second axis in the ordination space; the upper part of the plot shows a cluster (I) of specimens collected at sites of high contents of $CaCO_3$, exchangeable elements, and pH ranging within 5.5–7.8 (Fig. 2). The lower part of the plot shows another cluster (II) consisting of specimens that grew at sites devoid of carbonates and with pH within 4.4–6.9 (Table 4).

The first principal component combines the following 14 morphological characters: CH, IL, MSL, MSPL, LFSL, LFSW, LFSBL, LFSBSL, UFSL, UFSW, UL, UBL, FSGL, and MSGL (Table 5). The highest factor loadings on the second principal components are characteristic of soil parameters, particularly pH, $CaCO_3$, Mg, and Ca (Fig. 2B and Table 5).

A similar result was produced by the cluster analysis (Fig. 3). The dendrogram shows two groups of specimens collected from sites differing in their soil conditions. In addition, group I shows a subgroup (denoted Ia), consisting of individuals originating from sites with the highest $CaCO_3$ and Ca contents in the soil (sites 16 and 5), and a subgroups Ib consisting of specimens from sites 2, 4, 8, 10, 11, 12, and 14. Group II shows the presence of specimens from the same sites, scattered throughout the group in the dendrogram, signifying the lack of any clear-cut relationships between them (Fig. 3).

Significant morphological differences between specimens in group I (sites 2, 4, 5, 8, 10, 11, 12, 14, and 16) and II (sites 1, 3, 6, 7, 9, 13, 15, 17, 18, 19, and 20) were revealed in NFS, DUFS, CLL, MSW, CH, MSPL, UFSL, SFSBW, B/U, FSGW and MSL (Table 3). Cluster II contains specimens generally showing a higher number of crowded female spikes, shorter and narrower male spikes, longer leaf blades, and higher stems, as compared with the individuals in cluster I (Fig. 4). The subgroup Ia specimens differed significantly from those in subgroup Ib in the 17 characters (Table 3).

Table 5. Factor loadings onto principal component axes for 40 characters used in the principal components analysis. Values higher than |0.50| are set in boldface.

Characters	PC1	PC2	Characters	PC1	PC2
CH	**–0.5198**	–0.2898	SFSBL	–0.4726	–0.0300
CLW	–0.4157	–0.2118	SFSBW	–0.3296	–0.0109
CLL	–0.4460	–0.4315	UL	**–0.6882**	–0.2065
C/L	0.1354	0.0511	UBL	**–0.6682**	–0.1666
IL	**–0.5058**	–0.3438	B/U	–0.2972	–0.0029
MSL	**–0.6403**	–0.0578	FSGL	**–0.6931**	–0.0544
MSW	–0.2273	0.1281	FSGW	–0.4519	–0.2548
MSPL	**–0.5162**	0.1044	MSGL	**–0.5871**	–0.0509
NFS	0.1799	–0.4228	MSGW	–0.3999	–0.0213
DUFS	–0.4697	0.1831	C	–0.2735	0.4043
DLFS	–0.3260	–0.3678	H	–0.2584	**0.5477**
LFSL	**–0.6760**	–0.1942	N	–0.2093	0.4869
LFSW	**–0.6394**	–0.0873	C/N	–0.1906	0.4191
LFSPL	–0.3195	–0.2225	pH-KCL	–0.3276	**0.7427**
LFSBL	**–0.6121**	–0.3835	pH-H_2O	–0.2945	**0.724**
LFSBW	–0.4699	–0.2169	$CaCO_3$	–0.3842	**0.7296**
LFSBSL	**–0.5177**	–0.1835	P	–0.0073	0.1753
B/I	0.1337	–0.0483	K	0.1076	0.3313
UFSL	**–0.7099**	0.0404	Mg	–0.2798	**0.836**
UFSW	**–0.7411**	–0.0385	Ca	–0.3958	**0.758**

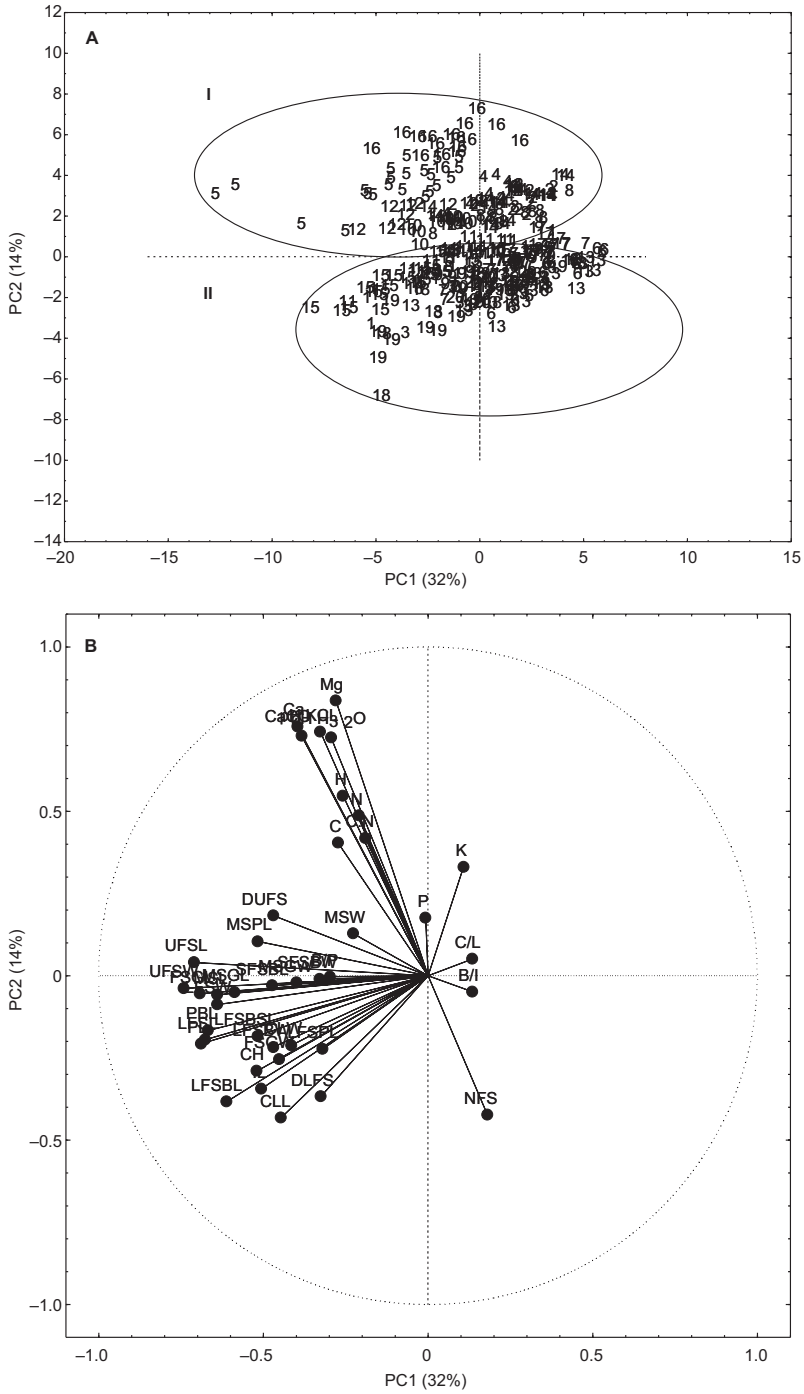

Fig. 2. (**A**) Two-dimentional PCA plot showing the two clusters (I and II) grouping specimens from sites with different soil parameters. (**B**) PCA plot showing the contributions of single characters. Group I: sites 2, 4, 5, 8, 10, 11, 12, 14 and 16; group II: sites 1, 3, 6, 7, 9, 13, 15, 17, 18, 19 and 20. *See* Table 1 and 4 for character codes.

Discussion

In Poland, *C. viridula* populations are found both on slightly acidic, low-carbonate (or carbonate-free) soils and on high-carbonate, high-calcium soils, along with *C. lepidocarpa*, the most calciphilous taxon within the *C. flava* complex. *Carex viridula* was occasionally reported from

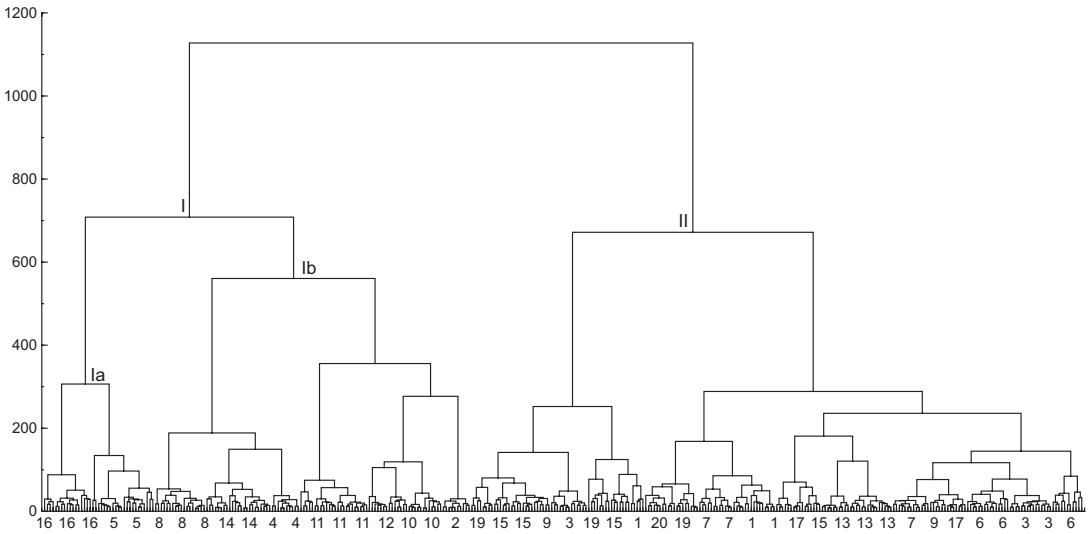

Fig. 3. *Carex viridula* cluster analysis. The hierarchical levels discussed in the text are marked with Roman numerals and letters.

salt marshes; however, due to the very low number of flowering individuals, the salt marsh population was not included in this study. *Carex viridula* occupies similar sites in other European countries (e.g. Davies 1956, Schmid 1984a, 1986). However, according to Davies (1956), an open community on low-acid soils is the commonest habitat for the sedge.

Carex viridula is highly morphologically variable; the range of variability is similar in different parts of the distribution range (e.g. Davies 1953b, Havlícková 1982, Crins & Ball 1989a, 1989b, Hedrén 2003, Więcław 2011). However, it should be noted that the variability patterns in *C. viridula* seem to be most complex in Scandinavia (Palmgren 1959, Pykälä & Toivonen 1994, Hedrén 2003).

While the morphological variability of *C. viridula* was studied by many authors, soil conditions that may explain it were seldom determined and analysed (e.g. Stoeva & Štepánková 1990). Soil pH was the parameter most frequently determined at *C. viridula* sites, but the possible pH effects on the sedge's morphology were not examined. According to Jermy *et al*. (2007), *C. viridula* is most frequent on acidic substrates. For comparison, the measured pH ranges at *C. viridula* sites were 5.4–8.5, 6.3–8.2, 5.2–7.6, 4.7–8.3, and 4.4–7.8 in the British Isles (Davies 1956), Switzerland (Schmid 1984b), North America (Crins & Ball 1989a), Bulgaria and Czechoslovakia (Stoeva & Štepánková 1990), and Poland (this study), respectively. Although the wide pH range seems to suggest then that soil pH is not a factor limiting the occurrence of *C. viridula*, according to our results sites with lower pH usually supported sedges with numerous (2–7; average of 4), tightly packed, long female spikes and with short and narrow, usually peduncle-less, male spikes. The distance between the female spikes (usually between the first and the second spike) was highly variable and should be interpreted with caution, as the coefficient of variation (CV) for this character exceeded 100% at sites 5 and 8, i.e. where soil pH exceeded 7.0, as well as at sites 1 and 3 with pH exceeding 6.0 and 4.5, respectively. The high CV at those sites resulted from the populations containing individuals with spikes set far apart, particularly at site 5 where the first and the second female spike were up to 7.0 cm apart.

Stoeva and Štepánková (1990) found a very weak correlation between environmental factors (pH and Ca^{2+}) and *C. viridula* morphology. Consequently, their cluster analysis showed *C. viridula* populations from extremely different sites placed side by side. Therefore, Stoeva and Štepánková (1990) are of the opinion that habitat parameters did not affect in any way the patterns of variability in the populations they studied.

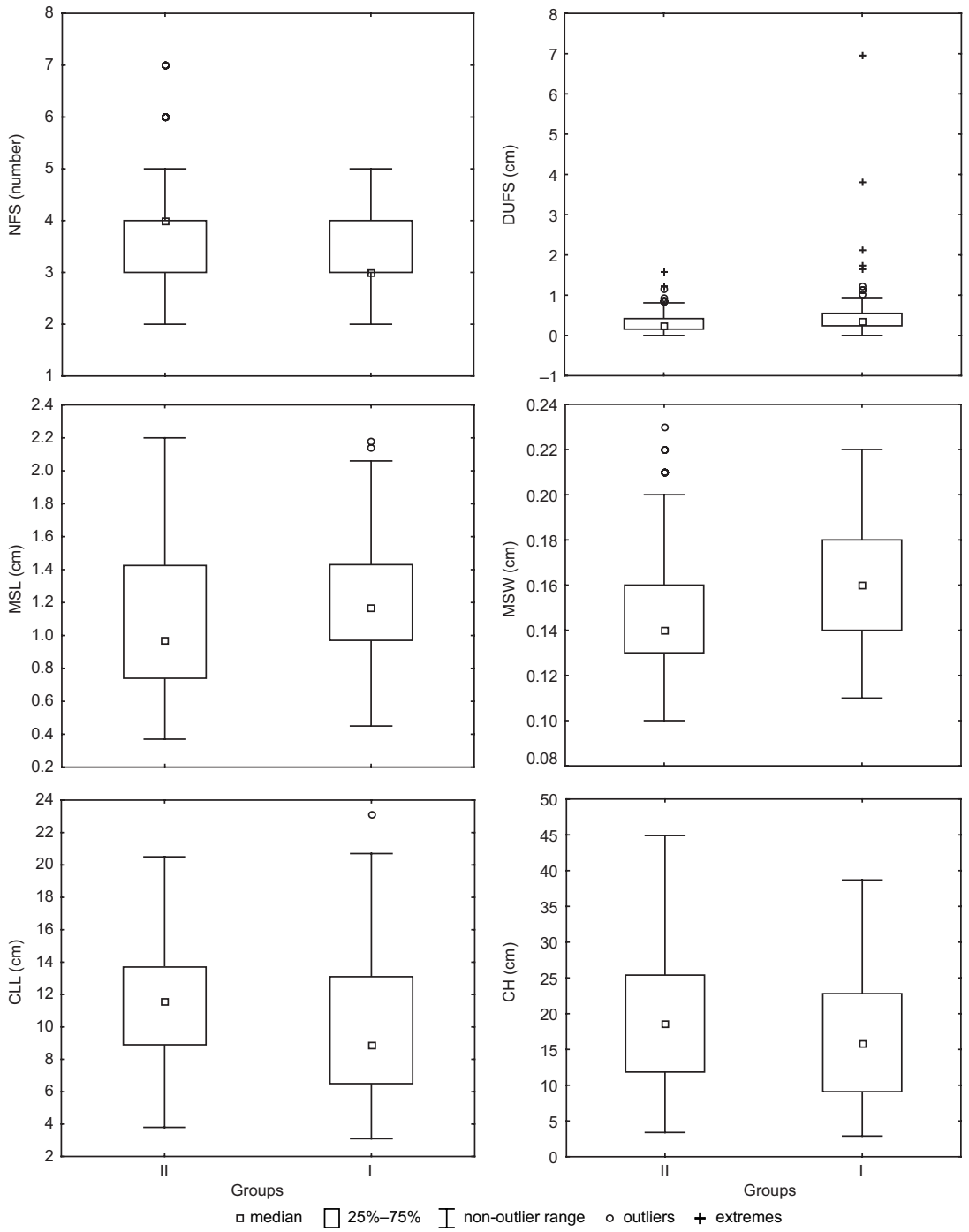

Fig. 4. Number of female spikes (NFS), distance between two upper female spikes (DUFS), male spikes length (MSL) and width (MSW), cauline leaves length (CLL) and culms height (CH) of *Carex viridula* in groups I (sites 2, 4, 5, 8, 10, 11, 12, 14) and II (sites 1, 3, 6, 7, 9, 13, 15, 17, 18, 19, 20).

In our study, sites with high-carbonate soil rich in exchangeable elements and with pH above 7.0 supported specimens with three or two (occasionally four) female spikes set far apart, as

well as with long male spikes, usually set on distinct peduncles. Calciferous sites, with sympatric occurrence of *C. viridula* and *C. lepidocarpa*, featured natural hybrids of variable morphology, which introduces an additional complication into the pattern of variability in the populations studied. However, the occasional hybrids are totally or partly sterile, and are frequently intermediate relative to the parents or morphologically close to *C. lepidocarpa*, and therefore identifiable (H. Więcław unpubl. data).

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